NASA’s Nuclear Systems Initiative

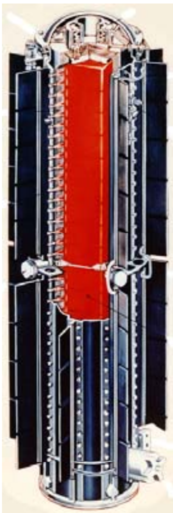
Overview

Nuclear Systems Initiative (NSI)

- Safety is the absolute highest priority
- Three components to this technology initiative
  - Radioisotope power development for potential use on Mars '09 and planetary exploration
  - Nuclear Fission Electric Propulsion research
  - Nuclear Fission Power research
- This initiative is in addition to the In-Space Propulsion Program already in the baseline

The Nuclear Systems Initiative will enable a new strategic approach to planetary exploration and is likely to play a key role in NASA's future

Nuclear Systems Enabling NASA's Quest for Life



RPS capabilities enable the search for life's origins on Mars

- *Enhance surface mobility*
- *Increased operational options: full-time science exploration*
- *More advanced instruments*
- *Longer life: more sites, more options, greater diversity*

Fission power and propulsion enables exploration not otherwise possible

- *Orbiting -- as opposed to fly-by -- missions*
- *Abundant power in deep space: more capable instruments, much greater data rates*
- *Reduced trip time: fast science return*
- *Multiple sites and sample return options*

Challenges of Solar System Exploration Beyond Mars

Characteristic	*Challenge*	*What we need:*
Distance	Solar power is impractical	Power where it's needed
	Flight times are long and gravity assist opportunities can be rare	Highly efficient electric propulsion
	Mass is limited, data rates are low	Increased payload/data return
Environmental extremes	Radiation and temperature Atmospheric and subsurface conditions	Increased mass for shielding and heat for thermal control
	Particle hazards	Robust mission and system designs that avoid or tolerate hazardous regions
Dynamic systems	Giant planet/ring/satellite/ magnetosphere systems Pluto/Charon and the Kuiper belt	New types of science and systematic study of multiple targets & processes

Power is essential to meet these challenges…

Why Does Power Matter?

Power is ENERGY for science, mobility, playback, etc.
Power is TIME for surface reconnaissance & discovery
Power is ACCESSIBILITY to the planet (latitude, terrain)
Power is RESILIENCY and ADAPTABILITY

The 2009 Mobile Surface Laboratory Mission:

- Search for evidence of life (hospitable environments, organics, etc.)
- RPS delivers the capabilities and **TIME** to maximize science yield

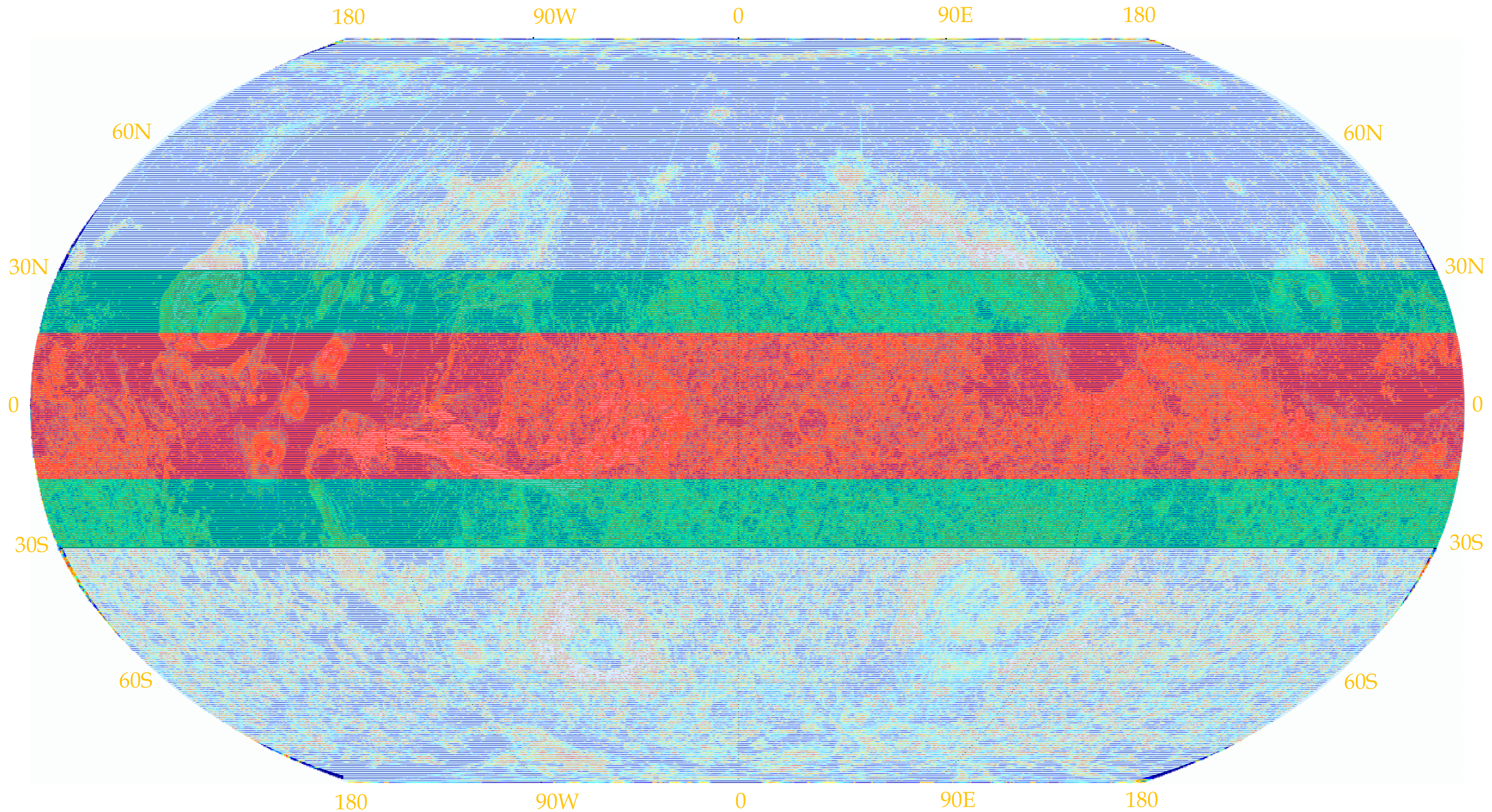
Solar

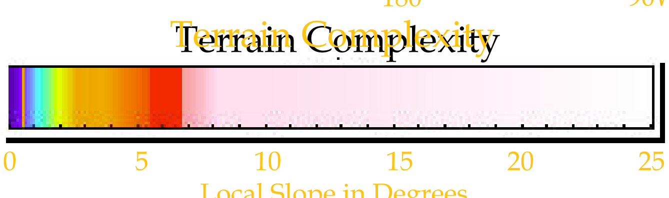
- **Baseline 180 days (daytime only)**
- **Equatorial landing site**
- **“Hostage to time” and power management**
- **Yield is 10’s of sensor suite analyses**

RPS

- **Continuous power for 1000+ days**
- **Landing anywhere, any season**
- **Time and power to test the “right stuff”**
- **Yield is order of magnitude greater (# of analyses, images, distance)**

Accessible Areas: Solar versus Nuclear



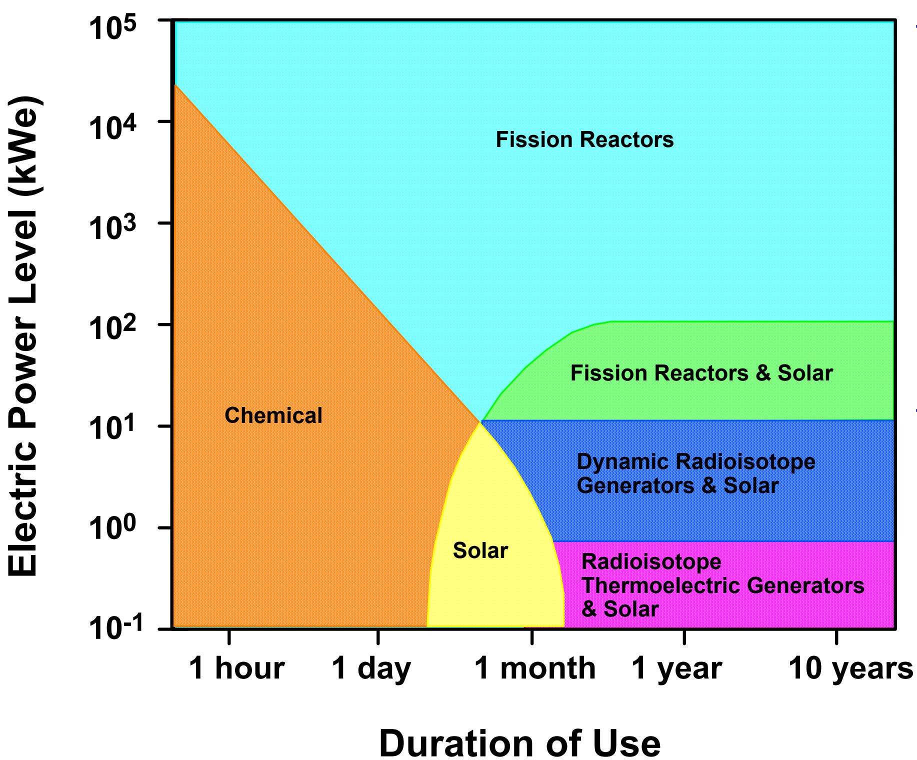


Solar at Adequate Power

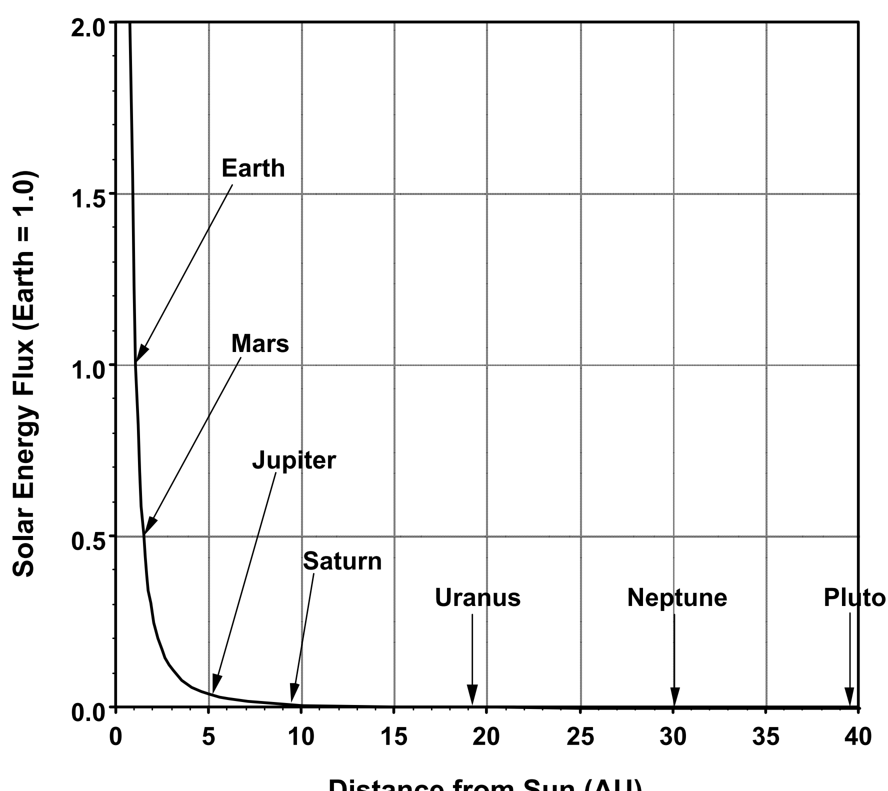
Solar at Marginal Power

RPS: All of the Planet, All of the Time

Why Use Nuclear Systems in Space?



- Long-duration operations (> 1 week)
- High sustained power (> 10-100 kWe)



- Distances where solar power density is too low (> ~1.5 AU)
- Locations where solar power not readily or continuously available (lunar polar craters, high Martian latitudes)

Radioisotope Power Development

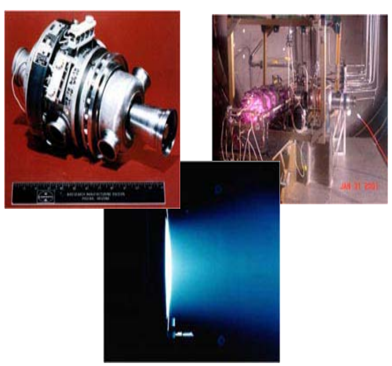
- Reestablish capability to produce radioisotope power systems for future solar system exploration missions.
  - Radioisotope power systems have been used by NASA for the past 30 years
- Radioisotope Power Development efforts focus on increasing the efficiency of future power conversion technologies.
  - Lower launch mass and plutonium usage
- First use of new radioisotope power system is being considered for the Mars 2009 Smart Lander.
  - Increases the Lander’s lifetime from 180 days (using solar panels) to greater than 1,000 days
  - Operates day/night and in all weather and latitudes

NASA Missions That Have Used RTGs

Missions		Launch Year	Type of RTG	Power Level Per Unit (We)	Thermoelectrics Used
NIMBUS	B-1	1968 (Aborted)	--	--	--
	III	1969	SNAP 19 (1)	~28	PbTe
APOLLO	11	1969	Heater Units	--	--
	12	1969	SNAP 27 (1)	~73	PbTe
	13	1970 (Aborted)	--	--	--
	14	1971	SNAP 27 (1)	~73	PbTe
	15	1971	⚐	⚐	⚐
	16	1972	⚐	⚐	⚐
	17	1972	⚐	⚐	⚐
PIONEER	10	1972	SNAP 19 (4)	~40	PbTe/TAGS
	11	1973	⚐	⚐	⚐
VIKING	1	1975	SNAP 19 (2)	~35	PbTe/TAGS
	2	1975	⚐	⚐	⚐
VOYAGER	1	1977	MHW (3)	~150	SiGe
	2	1977	⚐	⚐	⚐
GALILEO		1989	GPHS-RTG (2)	~285	SiGe
ULYSSES		1990	GPHS-RTG (2)	~285	SiGe
PATHFINDER		1996	Heater Units	--	--
CASSINI		1997	GPHS-RTG (3)	~285	SiGe

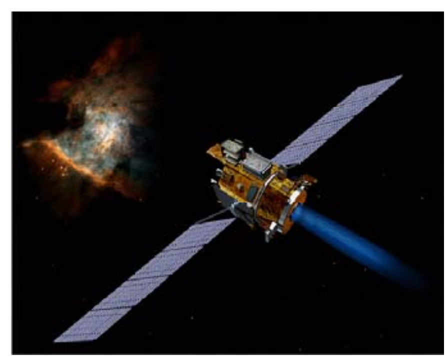
Nuclear Fission Electric Propulsion Research

- **Electric Propulsion provides dramatic advantages over chemical propulsion**
  - Enables new classes of solar system exploration missions with multiple targets
  - Eliminates or reduces launch windows required for gravity assists
  - Reduces cruise time to distant targets
  - Reduces mission cost because smaller launch vehicles may be used



Subsystem Technologies

Technology System Flight Validation



DS-1 Technology validation mission

Nuclear Fission Power Research

- **Nuclear Fission Power dramatically increases the scientific return of future missions**
  - Provides electrical power for the electric propulsion system
  - Greater operational lifetime increases the productivity of spacecraft and instruments
  - Enables multiple destinations on a single mission
  - Provides energy for high-power planetary survey instruments for remote sensing and deep atmosphere probes
  - Allows higher bandwidth communications

Nuclear Fission Power Research

- Nuclear power is the only option for outer planets exploration
- Provides 10’s KW electrical power for electric propulsion and operation of science instruments
  - Significantly more power than ~0.1 KW electrical from radioisotope power systems
- One U.S. nuclear fission power system was launched in mid-1960’s
  - Research was conducted through the early 1990’s (SP-100)
- Range of technical approaches available for reactor and power conversion to electricity. Require research of multiple approaches before down-selection to optimal design(s).
  - Perform parallel in-house and industry/academia/government studies (2-year effort)
- Need to survey and assess industrial base to identify potential suppliers and development needs
  - Special materials needed for space-based nuclear fission system
- Need to develop sufficient technical and industrial base (~3 year effort) to support an informed decision for development competition in 2006 timeframe

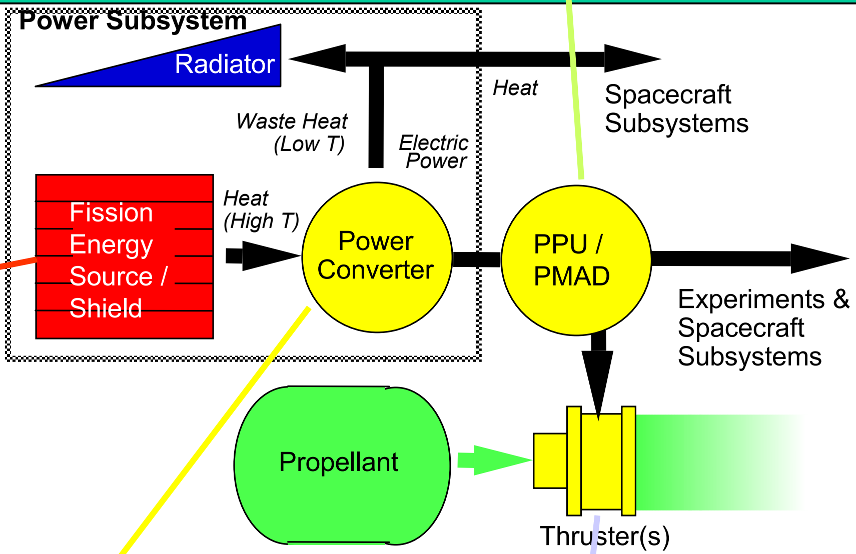
NEP System Overview and Technology Options

Nuclear Reactor (core) produces thermal energy via fission of U-235. Fission reaction rate (power) actively and passively controlled by neutron balance (produced vs lost). Reactor cooling system transports heat to power converter and maintains stable core temperature.

Reactor Cooling Options:

- Heat Pipe Cooled
- Direct Gas cooled
- Liquid Metal Cooled

Power Processing Unit and Power Management and Distribution (PPU / PMAD) dependent on power conversion and thruster subsystem choices. High Isp ion thrusters need high voltage (>4000 V).



Thruster uses electrical energy to produce thrust. Energy accelerates propellants achieving high exit velocities (Isp)

Options:

- Ion Engine
- MPD
- Hall
- VASIMR
- Pulsed Inductive Thruster

Power Conversion converts heat to electricity.

Options:

- Brayton - moderate/high power
- Thermionic Power Conversion
- Stirling - low/moderate power
- Thermoelectrics
- Rankine - Liquid Metal

NEP System Challenges

Developing NEP systems for space flight represents a unique systems engineering and integration challenge

- **Environments are extreme**
  - > Thermal subsystem design a challenge with large deployable radiators, nuclear subsystem, power conversion, and bus/payload thermal requirements
  - > Radiation environment compounded by presence of neutrons and gammas from reactor – dependent on vehicle configuration (boom) and shield mass. Demands stringent EEE parts requirements (SEE and total dose).
  - > These challenges exacerbated by long required lifetimes
- **Nuclear Safety**
  - > Driven by requirement for reactor to remain subcritical during all credible pre-launch and launch accidents/failures
- **Test and Verification Approach**
  - > Maximize use of non-nuclear testing to reduce costs
  - > Provide confidence in meeting lifetime requirements either through accelerated tests or performance degradation/extrapolation
- **Subsystem Impacts to Overall Vehicle Configuration**
  - > Radiator location, orientation and view factors
  - > Boom length versus shield mass
  - > Thruster location to direct thrust through cg, while keeping cg migration to minimum
  - > Plume impingement
- **Need for Deployable Mechanisms**
  - > Lightweight deployable radiators
  - > Boom
- **System-level Drivers on Power Conversion Subsystem**
  - > May force consideration of passive or other dynamic methods

NEP System Challenges

NEP systems require demanding performance

- **Specific impulse (Isp) in the range of 6000 to 9000 sec**
  - > Isp $\propto$ Exhaust momentum per unit mass of propellant (i.e., exhaust velocity)
  - > Isp is time that thruster can deliver 1 lbf of thrust with 1 lbm of propellant – quantifies how well propulsion system utilizes propellant
- **Alpha (α_{jet}) less than or equal to 50 kg/kW$_{jet}$**
  - > α_{jet} = mass of system/jet power of thruster exhaust (not input power to thrusters)
  - > System mass includes dry mass of reactor, shield, radiator, power conversion, thrusters/PPU, and PMAD
  - > Payload mass includes boom, spacecraft bus and subsystems, payload, and dry mass of propellant tanks
  - > $\alpha_{electric}$ = thruster efficiency • α_{jet}
- **Propellant throughputs of 2000 to 4000 kg, depending on mission and destination**
- **Operational lifetimes of 10 to 20 years, depending on mission and destination**

OSS Selection Process

- Requirements established by Space Science Strategic Plan and vetted by the National Academy of Sciences
- Technology research is openly competed, and is open to U.S. industry, universities, NASA Centers, FFRDCs, and other government agencies
- NASA HQ leads peer review and selection process
- The Office of Space Science competes 82% of its program

Nuclear Systems Initiative
Management Review

Chair:	Christopher Scolese, Deputy Associate Administrator for Space Science, NASA HQ
Vice-Chair:	Colleen Hartman, Solar System Exploration Division Director, NASA HQ Plaetary Science Representative
Members:	Earl Wahlquist, Associate Director for Space and Defense Power Systems, Office of Nuclear Energy, Science and Technology, Department of Energy
	Gerald Barna, Deputy Director, NASA GRC
	James Garvin, Mars Program Scientist, NASA HQ
	Eugene Tattini, Deputy Director, NASA JPL
	Wallace Sawyer, Associate Director, NASA KSC
	Robert Sackheim, Associate Director, NASA MSFC

Invited Representatives from the following NASA HQ Offices: Space Flight, Aerospace Technology, Safety and Mission Assurance, International Relations, Biological and Physical Research, Legislative Affairs and Public Affairs.

Summary

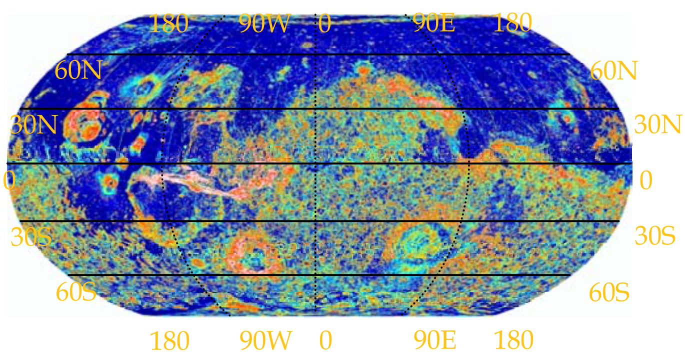
Development of RPS and NEP will revolutionize our ability to study the Solar System's natural laboratories.

Radioisotope power systems enable surface missions

Outer planetary exploration missions are enabled by NEP.

Continue the 30-year relationship with DOE in providing radioisotope systems for space exploration.

Space exploration, coupled with nuclear systems, has the potential for exciting a new generation of scientists and engineers in the nuclear field.



Mars Surface

Galilean Satellites

Titan